# CHARACTERISTICS OF MIXED EVERGREEN FOREST IN THE SONOMA MOUNTAINS OF CALIFORNIA

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ABSTRACT

Ten stands of mixed evergreen forest were sampled at 16 locations using belt transects to estimate density and basal area of overstory tree species, and small quadrats to estimate cover of understory species. Physical environmental variables were measured at each quadrat. Ordination based on overstory composition showed four distinct clusters, but that based on understory composition showed little differentiation. The overstory types included *Pseudotsuga*-hardwood and mixed hardwood phases, thus incorporating both north and south extremes of this wide-ranging forest type. No correlation was found between overstory or understory composition and measured site characteristics.

The mixed evergreen forest of California is a poorly defined and little-studied vegetation type covering large areas of the lower montane zone of the state. The type, in part, was probably first recognized by Cooper (1922) as his "broad-sclerophyll formation," which ranged from southern Oregon to northern Baja California. Cooper defined this formation primarily as being dominated by broad-sclerophyll trees (*Quercus, Lithocarpus, Arbutus,* and *Umbellularia*), with a small coniferous component (*Pinus* or *Pseudotsuga*) in its transitional limits in the North Coast Ranges and at its upper limits in the Sierra Nevada and Transverse Ranges. Munz and Keck (1949, 1950) were the first to define explicitly a Mixed Evergreen Forest Community on the basis of indicator dominants including a variety of broad-leaved evergreen trees (*Quercus, Lithocarpus, Arbutus, Umbellularia*), two broad-leaved deciduous trees (*Acer macrophyllum* and *Quercus kelloggii*), the conifer *Pseudotsuga menziesii,* and a variety of shrubs. Whittaker (1960) suggested a more restricted definition, to include only those forests with shared dominance between coniferous and broad-leaved evergreen trees. He recognized the type as transitional between sclerophyll vegetation and the montane and coastal coniferous forests, but argued for its being considered a formation in itself. Sawyer et al. (1977) have dealt most extensively with the community, and they used a broader definition. They rec-

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ognized mixed evergreen forest as typified by closed stands of broad-leaved sclerophyll dominants with a minor to significant conifer component. Their treatment also recognized two divisions of the type: the *Pseudotsuga*-hardwood forest, and the mixed hardwood forest. Barnhart (1978) adopted a similarly broad definition, viewing the mixed evergreen forest of the southern North Coast Ranges (especially in Sonoma County) as a series of associations ranging from mesic conifer-hardwood forest to more xeric hardwood woodland. For the present, we define "mixed evergreen forest" as any stand dominated by a mixture of coniferous and broad-leaved evergreen trees, or dominated by a mixture of broad-leaved evergreen trees with at least a small coniferous component.

The literature pertaining to mixed evergreen forests has been synthesized recently by Sawyer et al. (1977). A few published quantitative accounts of the community exist (e.g., Campbell 1980, Waring and Major 1964, Wells 1962, Whittaker 1960), but these deal with only the distributional limits of the community. No accounts are available of mixed evergreen forest—nor of many other communities—in the Coast Ranges between San Francisco and the Mendocino area. As part of a study of tree spatial patterning (Wainwright 1982, Wainwright and Pollock unpubl. data), we sampled several stands of mixed evergreen forest in the Sonoma Mountains. Our purpose was to characterize quantitatively the mixed evergreen forests found in that small but representative and central area.

## Methods

*Study site.* The study was carried out at Annadel State Park, located at the north end of the Sonoma Mountains, Sonoma County, California (Fig. 1). These mountains are low (maximum elevation ca. 650 m), with a north-south trend. The range is dominated by Pliocene Sonoma Volcanics overlying older sediments (Jenkins 1951). Climatic data have been recorded at two nearby stations: Santa Rosa, ca. 12 km west northwest of the park, and Sonoma, ca. 18 km southeast of the park (U.S. Weather Bureau 1964). Both stations show the Mediterranean-type precipitation pattern typical of most of California (Fig. 2). Though total annual precipitation is low (710–770 mm/yr), winter rainfall is abundant, averaging more than 150 mm in January. Temperatures are hot in summer (July mean daily maximum 28–29°C) and mild in winter (January mean daily minimum 2–3°C). The highest and lowest temperatures on record are 44°C and −9°C (for Santa Rosa). The area has a significant amount of frost: mean number of days with minimum temperature below 0°C is 47–48. The climate of the study site is expected to be generally similar to that of these stations, with some differences due to local topography.

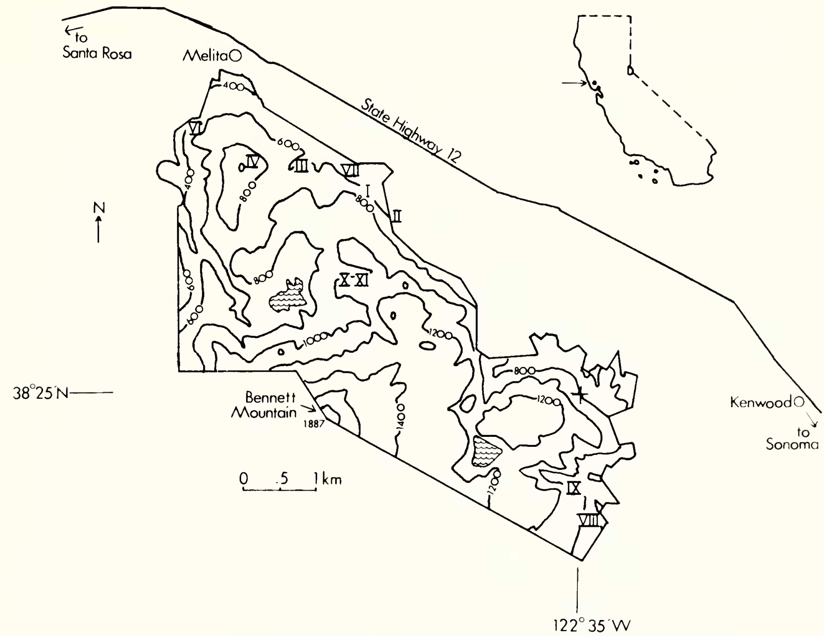


FIG. 1. Map of Annadel State Park. Roman numerals show approximate locations of sample stands. Elevations are in feet. Arrow and dot on inset map of California show location of the Sonoma Mountains.

The vegetation of Annadel is a complex mosaic of types including (using the nomenclature of Munz and Keck 1950) mixed evergreen forest, northern oak woodland, coastal prairie, valley grassland, chaparral, and freshwater marsh. Evergreen forest is generally restricted to the northerly slopes or tops of hills. South slopes are typically dominated by chaparral or grassland, and valley bottoms by oak woodland or grassland. Oak woodland also occupies many north slopes, particularly at higher elevations. Some of the oak-dominated communities on Bennett Mountain have been described by Tunison (1973), and his work is the only available description of vegetation in the park.

Little is known of the ecological history of the park. However, the recent human history of the park and its surroundings is well known, and has some ecological relevance. Prior to European settlement in the early 19th century, the area was inhabited by the Southern Pomo tribe of Native Americans. Annadel contains two small village sites, an obsidian quarry, and several work sites dating from this period (Wright 1975). Futini (1976) chronicled the history since that time. From the 1830s to the 1870s the park area apparently was used

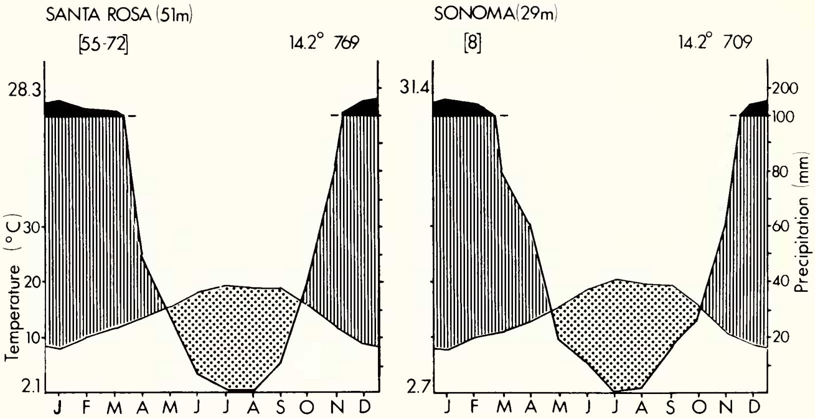


FIG. 2. Climate diagrams (after Walter 1979) for two nearby weather stations. Mean monthly precipitation (note scale change above 100 mm) and mean monthly temperature are given. Elevation follows station name. Duration of observations in years is in brackets below the station name (for Santa Rosa, first figure is for temperature, second for precipitation). Mean annual temperature and mean annual precipitation are at upper right. Along left margin, lowermost figure is mean daily minimum temperature for coldest month, uppermost is mean daily maximum temperature for hottest month. Period of relative drought is indicated by dot shading; relatively humid season is indicated by vertical shading. Data from U.S. Weather Bureau, 1964.

primarily for cattle grazing, with some quarrying of basalt. From 1870 to about 1920, quarrying for cobblestones and other building materials was the dominant business in the area, and several quarry sites are still apparent in the park. During this period, many of the hardwoods in the park area were cut for firewood. Around 1930, cattle ranching returned and continued as the dominant activity until the state park was established in the 1970s.

*Field methods.* Methods were chosen to serve two purposes: this vegetation description and a spatial pattern analysis of the tree dominants (Wainwright 1982; Wainwright and Pollock, unpubl. data). Ten forest stands were subjectively selected to reflect the ranges of canopy species composition and habitat (slope and aspect) for mixed evergreen forest at Annadel. Selections were restricted to stands of such size and uniformity that a variable-length transect up to 100 m long could be established without crossing any major transition in overstory composition. Accessibility was also a significant factor.

Mixed evergreen forest is typically composed of two layers: a usually dense tree overstory and a more-or-less sparse shrub and herb understory. These layers were treated separately in the data collection and analysis.

Trees were sampled using 5-m wide variable-length transects. From a randomly selected starting point within a given stand, a line was established approximately parallel to slope contours. Species, breast-height diameter (dbh), and distance along the line were recorded for each tree stem taller than 1 m that was encountered within 2.5 m on either side of the line. Each tree stem with no above-ground connection to another was counted as an individual, even though two or more nearby stems were sometimes clearly of the same genet. Stems with an above-ground connection were recorded as parts of the same individual. Transects were continued until either 132 trees had been recorded or a distinct change in overstory composition was reached. (The 132-tree limit was chosen for statistical reasons relating to the spatial pattern analysis.)

Understory plants were sampled using a 1 $m^2$ square-shaped quadrat laid at 20-m intervals (10 m in transect "1a") along the center line of each transect. In each quadrat, cover was estimated for each species of vascular plant, and for mosses as a group. At each quadrat, environmental factors (aspect, slope, estimated crown closure, and soil surface pH) were recorded, and soil samples were collected for the A horizon (usually ca. 6 cm deep). These samples were later analyzed for color, texture, and consistence and compared with descriptions of mapped soil units of the area (Soil Conservation Service 1972) to determine the soil type present.

Transects were replicated in some stands, for a total of 16 transects. (In one additional transect, "2b," only overstory data were collected.) Species nomenclature follows Munz (1973).

*Analytical methods.* To classify the stands, overstory and understory were treated separately. For the overstory, similarities of the 17 samples were calculated using Motyka's modification of Sorensen's index of similarity (IS) as described in Mueller-Dombois and Ellenberg (1974). Calculations were made based both on stem density and percent stem cover. These similarities were visually displayed as a two-dimensional ordination, using comparative stand ordination (Bray and Curtis 1957). Three ordinations were done: one based on stem density, one based on percent stem cover, and a composite using the average of the two IS values. From these results, samples were placed into groups showing high within-group IS values and low between-group IS values.

A similar procedure was used to classify the 16 understory samples, with the following differences: (1) the index of similarity was based on the mean percent cover of each species; and (2) the ordination had to be carried out to three dimensions to adequately represent the range of dissimilarity in understory composition.

## Results and Discussion

The overstory ordination based on percent stem cover and the composite ordination showed similar transect-clusterings, while that based on stem density showed little clustering. For grouping of stands,

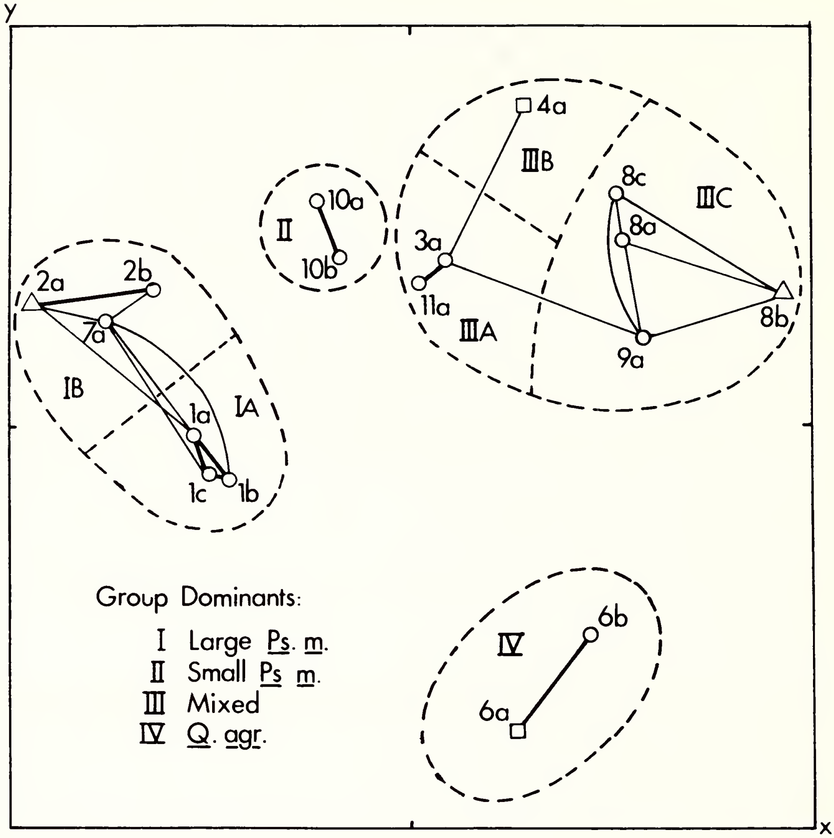


FIG. 3. Ordination of transects by overstory composition. Triangles mark endpoints of ordination on first (x) axis; squares mark endpoints on second (y) axis. Bold lines connect stands with IS values greater than 75%; light lines connect those with values between 60% and 75%. Dashed lines and Roman numerals indicate clustering as discussed in text. Arabic numerals with lower-case letters refer to individual transects.

the composite ordination (Fig. 3) was used because it shows the clearest separation of transect clusters. Four quite distinct clusters are apparent, two of which may be further subdivided.

These clusters may be typified as follows. Group I is dominated by large (30–170 cm dbh) *Pseudotsuga menziesii.* In the scheme of Sawyer et al. (1977), this group would fall under the broad heading "*Pseudotsuga*-hardwood forests," and is representative of the Klamath Mountains/North Coast Range phase of the forest type. Subgroup IA represents dense stands of *Ps. menziesii* with *Umbellularia californica* forming a sub-canopy. This type of forest is not recognized

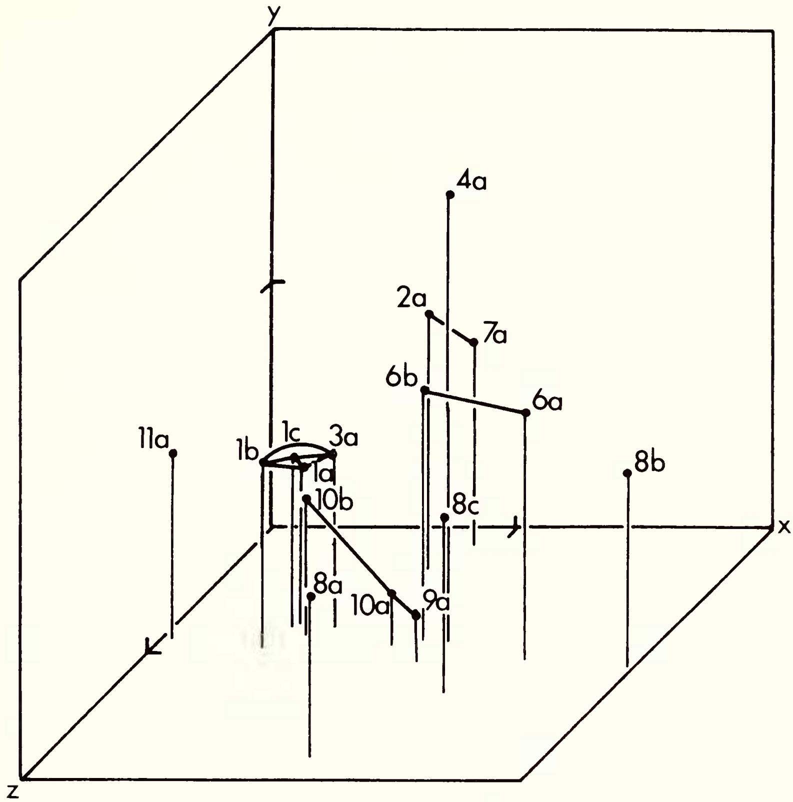


FIG. 4. Ordination of transects by understory composition. Endpoints used are: x-axis—11a and 8b; y-axis—9a and 4a; z-axis—7a and 8a. Bold lines connect points with IS greater than 50%. Numerals and letters refer to individual transects.

in the Sawyer et al. scheme, but is apparently structurally similar to their "*Pseudotsuga-Lithocarpus* forests." Subgroup IB represents open forest of almost pure *Ps. menziesii,* with a sparse mixture of broadleaf evergreens in the lower canopy layers. Group II also tends toward pure *Ps. menziesii,* but contains dense stands of small (less than 20 cm dbh) *Pseudotsuga* with significant amounts of *Umbellularia, Quercus kelloggii,* and *Quercus garryana*; this group would also fall under the "*Pseudotsuga*-hardwood" heading.

Group III is a cluster of mixed stands, each containing a significant amount of *Q. kelloggi.* Sub-group IIIA is co-dominated by *Ps. menziesii, U. californica,* and *Q. kelloggi*; IIIB is dominated by *Q. kelloggi,* with some *Ps. menziesii* and *U. californica*; IIIC is very mixed, each stand consistently containing six tree species. This group appears to be transitional between *Pseudotsuga/Umbellularia* forest

TABLE 1. TRANSECT SUMMARY. Overstory group refers to Fig. 3. Notes: 1. Dash indicates no data collected. 2. Soil types: Fo—Forward gravelly loam; Gg—Goulding clay loam; Gl—Goulding cobbly clay loam; La—Laniger loam; Sk—Spreckels loam. 3. Geological substrates: Tertiary: Tsa—andesitic to basaltic lava flows; Tsag—agglomerate with volcanic breccia and tuff breccia; Tsrp—perlitic rhyolite; Tst—pumicitic ash-flow tuff. Quaternary: QTge—fluviatile gravel, sand, silt, and clay with locally interbedded tuff (from Fox et al., 1973). 4. For overstory, upper figure is density (#/ha), lower figure is total basal area ($m^2$/ha).

| Overstory group: | I | | | | | | II | | III | | | | | | | IV | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | | | B | | | | | A | | B | C | | | | | |
| Transect: | 1a | 1b | 1c | 7a | 2a | 2b | 10a | 10b | 11a | 3a | 4a | 8a | 8b | 8c | 9a | 6a | 6b |
| Strip length (m) | 351 | 275 | 272 | 99 | 243 | 328 | 103 | 100 | 114 | 142 | 159 | 59 | 62 | 73 | 106 | 149 | 150 |
| No. of quadrants | 23 | 14 | 14 | 6 | 13 | 0 | 6 | 6 | 6 | 7 | 8 | 4 | 4 | 4 | 6 | 8 | 8 |
| Mean slope (%) | 41 | 38 | 46 | 42 | 24 | —[1] | 50 | 38 | 56 | 60 | 30 | 39 | 19 | 40 | 59 | 24 | 23 |
| Average aspect | N | NE | NE | E | N | — | N | N | N | N | NE | E | E | E | N | NE | NE |
| Mean pH of soil | 6.5 | 6.5 | 6.6 | 6.3 | 6.2 | — | 6.6 | 6.7 | — | 6.6 | 6.6 | 6.9 | 6.5 | 6.9 | 6.5 | 6.5 | 6.4 |
| Soil type[2] | Gl | Gl | Gl | Sk | Sk | — | Sk | Sk | Sk | Gg | Gg | La | La | La | Fo | Gg | Gg |
| Geological substrate[3] | Tsa | Tsa | Tsa | Tsa Tsag | Tsa QTge | Tsa QTge | Tsrp | Tsrp | Tsrp | Tsa | Tsa | Tst | Tst | Tst | Tst | Tsag | Tsag |
| Overstory composition[4] | | | | | | | | | | | | | | | | | |
| *Umbellularia* | 530 | 630 | 740 | 180 | 40 | 70 | 270 | 350 | 930 | 990 | 290 | 540 | 710 | 250 | 760 | 600 | 570 |
| *californica* | 6 | 8 | 13 | 0 | 0 | 1 | 2 | 2 | 11 | 10 | 6 | 6 | 5 | 2 | 7 | 0 | 5 |
| *Pseudotsuga* | 190 | 180 | 200 | 240 | 430 | 370 | 1710 | 1820 | 860 | 460 | 260 | 1020 | 130 | 600 | 320 | 70 | |
| *menziesii* | 50 | 78 | 68 | 76 | 61 | 43 | 27 | 17 | 17 | 6 | 6 | 3 | 0 | 9 | 2 | 0 | |
| *Quercus* | | | | 80 | 30 | 90 | 290 | 140 | 260 | 340 | 1050 | 510 | 620 | 630 | 340 | 30 | 80 |
| *kelloggii* | | | | 10 | 1 | 4 | 9 | 7 | 17 | 16 | 19 | 23 | 10 | 12 | 7 | 1 | 6 |
| *Heteromeles* | 10 | 20 | | | | | 40 | | 40 | 30 | 10 | 440 | 1560 | 1530 | 470 | 10 | 50 |
| *arbutifolia* | 0 | 0 | | | | | 0 | | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 |
| *Quercus* | 10 | | | 120 | 20 | 80 | | | | | | 170 | 60 | 220 | 40 | 640 | 680 |
| *agrifolia* | 0 | | | 2 | 0 | 1 | | | | | | 1 | 1 | 3 | 1 | 26 | 17 |

TABLE 1. CONTINUED.

| Overstory group: | I | | | | | | II | | III | | | | | | | IV | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | | | B | | | | | A | | B | C | | | | | |
| Transect: | 1a | 1b | 1c | 7a | 2a | 2b | 10a | 10b | 11a | 3a | 4a | 8a | 8b | 8c | 9a | 6a | 6b |
| *Quercus* | 10 | | | 60 | | 10 | 230 | 480 | 40 | | 10 | | | 30 | | | 30 |
| *garryana* | 0 | | | 1 | | 0 | 7 | 17 | 2 | | 0 | | | 0 | | | 0 |
| *Arbutus* | | | | | 60 | 180 | 20 | 60 | | | | 580 | 1230 | 330 | 280 | | 110 |
| *menziesii* | | | | | 0 | 2 | 1 | 3 | | | | 12 | 15 | 7 | 8 | | 0 |
| *Sequoia* | | 140 | 30 | | | | | | 140 | | | | | | | | |
| *sempervirens* | | 20 | 3 | | | | | | 12 | | | | | | | | |
| *Amelanchier* | | | | | | | | | 40 | 10 | | | | | 280 | | |
| *pallida* | | | | | | | | | 0 | 0 | | | | | 0 | | |
| *Arctostaphylos* | | | | | | | | | | | 10 | | | | | | 30 |
| *manzanita* | | | | | | | | | | | 0 | | | | | | 0 |
| *Aesculus* | | | | | | | | | | | | 30 | | | | | |
| *californicus* | | | | | | | | | | | | 0 | | | | | |
| *Fraxinus* | 10 | | | | | | | | | | | | | | | | |
| *latifolia* | 0 | | | | | | | | | | | | | | | | |

and *Q. kelloggi* woodland. In fact, Group IIIB could be considered as strictly oak woodland, were it not for the component of small-statured *Ps. menziesii* and *U. californica.* [Tunison (1973) noted the recent increase of both of these evergreen species in oak communities, and suggested that this could result from a recent development of a closed oak canopy producing an increasingly mesic understory. He also suggested that it is likely that mixed evergreen forest will eventually replace these communities.] Group IV represents two broad-leaved stands dominated by *Quercus agrifolia* with *U. californica* sub-dominant. This would be included under the "mixed hardwood forests" by Sawyer et al., and is representative of the South Coast Range/Southern California phase of the forest type; but it again is not a species combination they mention. A similar type in the Berkeley Hills has been discussed by McBride (1974), who suggested that *U. californica* is replacing *Q. agrifolia* in oak woodlands.

The ordination based on understory similarities (IS) is shown in Fig. 4. Overall, the understory samples were quite diverse: the highest similarity was 70%, and only 10 sample-pairs (out of 120) showed greater than 50% similarity. Consequently, little clustering was observed, and no general classification of the understory was possible. Clearly, much of this diversity may result from the small size (4–23 $m^2$) of the samples taken. These samples are not minimal area (suggested to be 50–200 $m^2$ for temperate forest understories by Mueller-Dumbois and Ellenberg 1974), so the ordination represents only the most common species of each stand.

Table 1 summarizes the composition of overstory transects with species listed in order of constancy. Clear group segregations are noted by underlining. Of the overstory species, only *U. californica* occurred in every stand, although *Ps. menziesii* and *Q. garryana* occurred in all groups and subgroups.

Understory composition showed little segregation by overstory group (Wainwright 1982). Of about 60 species encountered in the understory, nine (*Rhus diversiloba, Melica torreyana, Osmorhiza chilensis, Galium californicum, Symphoricarpos mollis, Torilis arvensis, Vicia* sp., *Cynosurus echinatus,* and *Dryopteris arguta*) occurred in every overstory group and subgroup. A few species, however, clearly segregated: *R. diversiloba* and *Festuca californica* both reached their highest cover in subgroup IIIB, *Bromus diandrus* is characteristic of subgroup IB, and *Polystichum munitum* is characteristic of IA.

Table 1 also includes a summary of physical environmental factors. There are no striking correlations between any of these factors and overstory or understory composition. Several factors could be responsible for this. The area studied is quite diverse in geologic substrate and topography. The area also has a long history of human use that could locally influence vegetation. Other historical factors may also be involved.

Lack of specific information regarding human and other disturbances is a major drawback in the analysis. Clearly, the vegetation analyzed is transitional, and composition might be much different if the site had had no human usage. As was noted earlier, the park holds several abandoned quarries, which were avoided in our sampling. However, the associated impacts of wood cutting (mostly prior to 1920—Futini 1976) were unavoidable: there was evidence of past cutting of *U. californica, Q. kelloggii,* and *Sequoia sempervirens* in all stands in which they occurred. There was also evidence of past fire in some stands. The combination of known selective removal of species and unknown occurrences of other disturbances make successional interpretation of our data impossible without thorough knowledge of age-structures of the populations involved.

There is much room for further study of woodland and forest communities in the Coast Range near San Francisco Bay. First, basic descriptive work is needed, followed by study of the dynamic relationships among the various communities. While our data provide no conclusions regarding such relationships, there are indications (Barnhart 1978, McBride 1974, Tunison 1973) of a successional trend from oak woodland to mixed evergreen forest. However, as Barnhart (1978) pointed out, the diverse nature of plant communities in the region makes conclusive study of successional trends quite difficult.

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